Sampling Based Trajectory Planning for Robots in Dynamic Human Environments

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Sampling Based Trajectory Planning for Robots in Dynamic Human Environments

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***Abstract*— Open-ended human environments, such as pedestrian streets, hospital corridors, train stations etc., are places where robots start to emerge. Hence, being able to plan safe and natural trajectories in these dynamic environments is an important skill for future generations of robots. In this work the problem is formulated as planning a minimal cost trajectory through a potential field, defined from the perceived position and motion of persons in the environment. A modified Rapidly-exploring Random Tree (RRT) algorithm is proposed as a solution to the planning problem.**

The algorithm implements a new method for selecting the best trajectory in the RRT, according to the cost of traversing a potential field. Furthermore the RRT expansion is enhanced to direct the search and account for the kinodynamic robot constraints. A model predictive control (MPC) approach is taken to accommodate for the uncertainty in the dynamic environment.

The planning algorithm is demonstrated in a simulated pedestrian street environment.

I. Introduction

As robots integrate further into our living environments, it becomes necessary to develop methods that enable them to navigate in a safe, reliable, comfortable and natural way around humans.

One way to view this problem is to see humans as dynamic obstacles in an uncertain environment. Obstacles that have social zones [2], which must be respected. Such zones can be represented by potential fields [5, 6], for which an example is shown in Fig. 1.

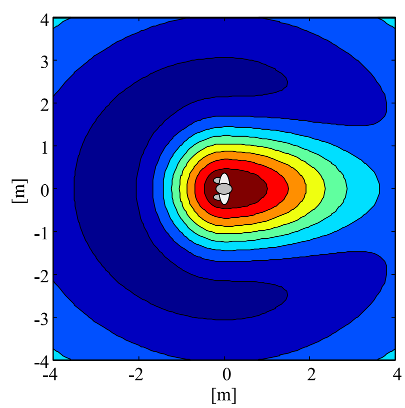

Fig. 1. Potential field around a person standing at $(0, 0)$ and looking to the left. The robot should try to get towards the lower points, i.e. the dark blue areas.

II. Navigation Algorithm

The navigation problem through an environment with many people, can then be formulated by summing potential fields for all the people in the environment, plus a potential for the desired robot motion in environment. An example of this, together with three possible trajectories for a robot, is shown in Fig. 2. Notice, that even though a trajectory passes through a person, it might not be a bad trajectory, since the person may have moved when the robot reaches the point.

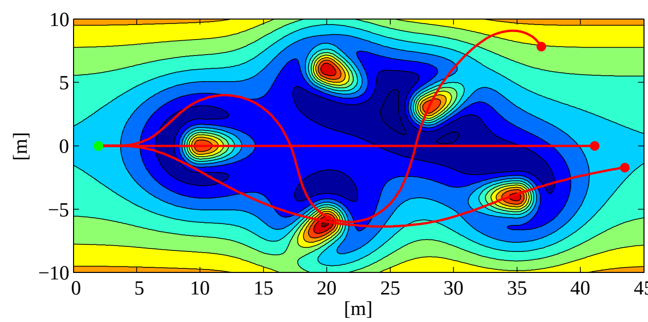

Fig. 2. Person landscape, which the robot has to move through. The robot starting point is the green dot at the point $(2, 0)$. Three examples of potential robot trajectories are shown. Even though it looks like the trajectories goes through the persons, this is not necessarily the case, since the persons might have moved, when the robot comes to the point.

Given the dynamic nature of the problem, robotic kinodynamic and nonholonomic constraints must also be considered. To take into account, the uncertainty in the environment, the dynamics of the robot, the potential field and the change over time, a standard RRT algorithm [4, 3] is modified in the following way:

- The planner runs in configuration-time ($\mathcal{C} - \mathcal{T}$) space, where moving obstacles are static [7]
- Person motion models are used to predict trajectories of persons
- When expanding the RRT, a 2. order dynamic motion model of the robot is used to predict the robot motion
- RRT vertices are pruned where the cost is too high
- A "best trajectory" is chosen based on the cost of traversing the trajectory, and not based on reaching a goal
- Using a Model Predictive Control (MPC) scheme, a new "best trajectory" is calculated on-line, while executing

the planned trajectory. After a short time period, the trajectory is replaced by the new “best trajectory”. And again a new RRT is initialised by seeding with the new “best trajectory”

- The environment potential changes over time according to the desired destination, which also make the algorithm robust to local minima.

Fig. 3 shows an example of a generated RRT, where the green trajectory it the one with the minimum cost.

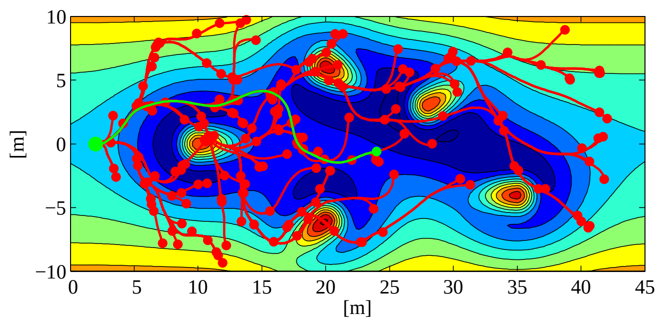

Fig. 3. An RRT for a robot starting at $(2, 0)$ and the task of moving forward through the human populated environment. Only every 10th vertex is shown to avoid clutter of the graph. The vertices are the red dots, and the lines are the simulated trajectories. The green trajectory is the least cost trajectory.

III. Simulation

The algorithm has been implemented and demonstrated in an experiment, where the robot plans the trajectory through a simulated pedestrian street. The environment has been simulated with a Poisson distributed number of persons entering and leaving the environment and with the persons not taking into account the motion of the robot. Fig. 4 shows a scene from the simulation. Through 50 simulations of a one minute period, the robot never runs into any persons. 98% of the time the robot keeps at least $1.2m$ to the nearest person, which is the boundary between the personal and the social zone according to Hall’s social distances [1, 2]. This demonstrates that the algorithm is able to plan a trajectory, which is safe and natural, through an uncertain human environment.

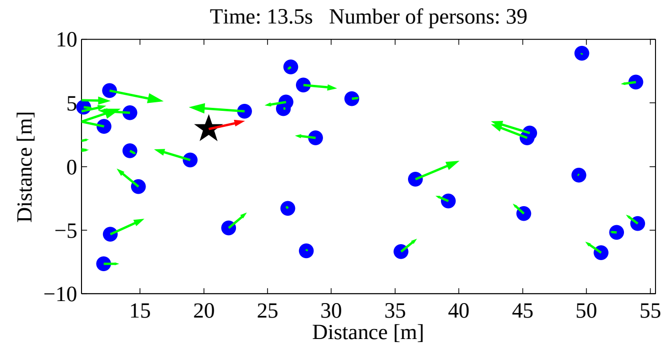

Fig. 4. The figure shows a scene from one of the 50 simulations. The blue dots are persons, with their corresponding current velocity vectors. The black star is the robot.

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